the combining can include using a low frequency waveform to modulate the magnitude of a higher frequency waveform. The low frequency and higher frequency waveforms can be filtered using a low pass and high pass filters. A haptic feedback interface device of the present invention can include a sensor, an actuator device, and controller that provide these features.

[0012] In another aspect of the present invention, a method combines two or more tactile sensations to be output by a haptic feedback interface device. A plurality of commanded haptic effects are to be output simultaneously by said haptic feedback interface device to a user. Each of the effect waveforms is filtered using a low pass filter and a high pass filter to produce a low passed waveform and a high passed waveform for each effect waveform, and, for each effect, the high passed waveform from a particular effect waveformn is multiplied with an envelope comprised of a summation of the low passed waveforms from each of the other effect waveforms, producing a plurality of product waveforms. The plurality of product waveforms are summed to produce an output waveform that is provided for output by an actuator device to a user of the tactile feedback interface device.

[0013] The present invention advantageously provides enhanced haptic feedback sensations for a haptic feedback device by creating higher strength low frequency sensations. This is accomplished by combining a high frequency with the commanded low frequency to create stronger sensations at the desired low frequency. Furthermore, the present invention allows two or more tactile sensations to be combined without significantly reducing the effectiveness or fidelity of the resulting output sensation.

[0014] These and other advantages of the present invention will become apparent to those skilled in the art upon a reading of the following specification of the invention and a study of the several figures of the drawing.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] **FIG. 1** is a perspective view of system including a haptic interface device of the present invention connected to a host computer;

[0016] **FIG. 2** is a side cross sectional view of the haptic interface device of **FIG. 1**;

[0017] **FIG. 3** is a perspective view of one embodiment of an actuator assembly suitable for use with the present invention;

[0018] **FIG. 4** is a block diagram illustrating an embodiment of the haptic interface device and host computer for use with the present invention;

[0019] **FIGS. 5*a*-5*c*** are graphs illustrating a method of the present invention of using resonance pulse bursts to provide stronger low frequency tactile sensations;

[0020] **FIGS. 6 and 7** are graphs illustrating another method of the present invention for providing a strong low frequency tactile sensation by adding it with a higher frequency sensation;

[0021] **FIG. 8** is a graph illustrating high and low pass filters used in another method of the present invention for providing strong low frequency tactile sensations or combining tactile sensations;

[0022] **FIG. 9** is a graph illustrating a low frequency commanded waveform and a higher frequency waveform to be combined with the low frequency waveform;

[0023] **FIG. 10** is a graph illustrating a modulation envelope resulting from filtering the low frequency waveform of **FIG. 9**;

[0024] **FIG. 11** is a graph illustrating a waveform resulting from the sum of products method of the present invention;

[0025] **FIG. 12** is a graph illustrating the waveform of **FIG. 11** when using normalized terms;

[0026] **FIG. 13** is a graph illustrating the waveform of **FIG. 12** after having been combined again with the higher frequency waveform of **FIG. 9**;

[0027] **FIG. 14** is a graph illustrating another example of a low frequency commanded waveform and a higher frequency waveform to be combined with the low frequency waveform;

[0028] **FIG. 15** is a graph illustrating the combined normalized result of the sum of products method using the waveforms of **FIG. 14**; and

[0029] **FIG. 16** is a block diagram illustrating the sum of products method of the present invention for combining waveforms.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0030] **FIG. 1** is a perspective view of a tactile feedback interface system **10** of the present invention capable of providing input to a host computer based on the user's manipulation of the interface device and capable of providing tactile feedback to the user of the system based on events occurring in a program implemented by the host computer. System **10** includes a device **12** and a host computer **14**. In the described embodiment of **FIG. 1**, device **12** is a mouse, but can be other types of devices as discussed below.

[0031] Device **12** is an object that is preferably grasped, gripped, or otherwise physically contacted and manipulated by a user. For example, a user can move mouse **12** to provide planar two-dimensional input to a computer system to correspondingly move a computer generated graphical object, such as a cursor or other image, in a graphical environment provided by computer **14** or to control a virtual character, vehicle, or other entity in a game or simulation. In other embodiments, a joystick, knob, wheel, button, or other user manipulandum may be moved. In addition, device **12** preferably includes one or more buttons **16*a*** and **16*b*** to allow the user to provide additional commands to the computer system. A scroll wheel, analog buttons or other inputs, or other controls can also be included.

[0032] Device **12** preferably includes an actuator assembly which is operative to produce forces on the device **12** and tactile sensations to the user. One example of an actuator assembly is described below with reference to **FIG. 3**.

[0033] In some embodiments, such as a mouse, device **12** rests on a ground surface **22** such as a tabletop or mousepad. A user grasps the mouse **12** and moves the mouse in a planar workspace on the surface **22** as indicated by arrows **24**. Device **12** can be a relative sensing device or an absolute